

Semi-Annual Report
July - December 1996

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Abstract

Our major achievements of this semi-annual period were: (i) the completion of the MODIS cloud retrieval ATBD revision (version 4), (ii) the participation in a July aerosol deployment known as TARFOX (Tropospheric Aerosol Radiative Forcing Observational Experiment), which included a quick-look data processing system for use in the field, (iii) the progress of product QA and Level-3 aggregation studies, and (iv) the presentation (as group activities) of seven papers in the 1996 International Radiation Symposium, two papers in the SPIE calibration conference, and three papers in the SCAR-B Science Symposium.

I. Task Objectives

With the use of related airborne instrumentation, such as the MODIS Airborne Simulator (MAS) and Cloud Absorption Radiometer (CAR) in intensive field experiments, our primary objective is to extend and expand algorithms for retrieving the optical thickness and effective radius of clouds from radiation measurements to be obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS). The secondary objective is to obtain an enhanced knowledge of surface angular and spectral properties that can be inferred from airborne directional radiance measurements.

II. Work Accomplished

a. MODIS-related Algorithm Study

Since the initial MODIS cloud retrieval v1 code delivery to the SDST on 6 May, we have found and corrected a couple of core dump errors when running with MAS data for various pixel sizes. The final v1 package was re-delivered to SDST on 6 August and accepted by the Configuration Manager. Ran Song (new member) constantly checked our software delivery code (MOD_PR06OD) and modified it as required to meet further MODIS software standards, as well as to finalize the file specification for the v2 code delivery, which included incorporation of quality assessment (QA) flags. The first draft of the MOD_PR06OD file specification and first version of our QA plan were completed. Table 1 shows the QA for MOD_PR06OD in two integers. The first integer is the Product Main QA Flag which is two bytes long and contains the Cloud Mask information and Processing Path Flags (the first 8 bits from the MODIS cloud mask product), and MOD_PR06OD Product Main Run Time QA Flags. The second integer is the Product Optional Run Time QA Flag, and is three bytes long. The DAO data will

be the primary ancillary data to be used in generating product MOD_PR06OD. Although primary information has been obtained, there is still a lack of some important information such as data resources and detailed schemes used to produce the data; these are required to further implement MOD_PR06OD and for diagnostic studies. These variables are written as arrays containing values for each pixel in a granule.

Table 1. (a) Product Main QA Flag

QA Flag Name	Number of Bits	Bit Value	Description
Cloud Mask	1	0 1	Undetermined Determined
Cloud Mask Quality Flag	2	0 1 2 3	Cloudy 66% clear 95% clear 99% clear
PROCESSING PATH FLAGS			
Day/Night flag	1	0 1	Night Day
Sun glint flag	1	0 1	Yes No
Snow/Ice flag	1	0 1	Yes No
Land/Water flag	2	0 1 2 3	Water (ocean) Coastal Wetland Land
PRODUCT RUN TIME QA FLAGS			
Optical Thickness General QA	1	0 1	not useful useful
Optical Thickness Confidence QA	3	0-7	8 confidence levels
Effective Radius General QA	1	0 1	not useful useful
Effective Radius Confidence QA	3	0-7	8 confidence levels

Table 1. (b) Product Optional Run Time QA Flag

QA Flag Name	Number of Bits	Bit Value	Description
PROCESSING PATH FLAGS			
Water/Ice Cloud	2	0 1 2 3	No Information water cloud ice cloud mixed phase cloud

Rayleigh Correction	1	0 1	No Yes
Water Vapor Correction	1	0 1	No Yes
Band Used for Optical Thickness Retrieval	2	0 1 2 3	Not retrieved 0.645 μm (land) 0.858 μm (water) 1.24 μm (snow/ice)
Spare	2		
DATA RESOURCE FLAGS			
Moisture profile	2	0 1 2 3	MOD07/MOD05 MODANC_ATMOS_L2 DAO Standard Atmosphere
Cloud Top Height	2	0 1 2 3	MOD06 (Menzel) DAO N/A
Temperature Profile	2	0 1 2 3	MOD07 MODANC_ATMOS_L2 DAO Standard Atmosphere
Surface Temperature Over Land	2	0 1 2 3	MODANC_ATMOS_L2 DAO N/A
Surface Temperature Over Ocean	2	0 1 2 3	MOD28 MODANC_ATMOS_L2 DAO N/A
BRDF/Albedo	2	0 1 2 3	MOD43 MODANC_ATMOS_L2 DAO N/A
Ozone profile	2	0 1 2 3	DAO TOMS N/A
Spare	2		

Xu Liang (new member) finished the analysis of the processing model that is most appropriate for MODIS Atmosphere Level-3 aggregation. The “tile” approach was then proposed to Rich Hucek for use, as opposed to the “orbit approach.” The Data Assimilation Office was consulted to help select preferred

Level-3 parameters to be aggregated from the potential GCM applications point of view. The idea behind this was to get input from GCM community to make the MODIS Atmosphere Level-3 products more useful to the wider scientific community. These selections from DAO are due in January 1997. Thus, the final list of parameters for Level-3 will be based on input from the Atmosphere group as well as from the GCM community. In addition, the wavelets method was studied to explore the feasibility of using wavelets in the aggregation of the MODIS Level-3 atmosphere product.

Regarding atmospheric absorption correction of MOD_PR06OD, the sensitivity of atmospheric transmittance to H₂O and CO₂ was studied for MAS band 7, 10, 20 and 31 by applying correlated-k-distribution calculations. Several standard atmospheric soundings will be used for band transmission fitting calculations.

b. MODIS-related Instrumental Research

After the new port 1 silicon array (with blue channel) was installed, the MAS was operated successfully in the TARFOX campaign, based at NASA Wallops Flight Facility during 10-30 July 1996. From the MAS quicklook images, we confirmed that the blue channel behaved quite well, as expected. Post-flight calibrations for TARFOX were performed at the Ames Research Center, analyses of which are currently underway. The Ames Calibration Lab (Pavel Hajek, engineer) is also researching a high temperature blackbody source for use in calibrating MAS, required to support biomass combustion studies. This would entail a small aperture blackbody whose output is expanded and collimated to fill the full input aperture of the MAS.

Ames (Jeff Myers) plans to upgrade the MAS in the Fall/Winter of 1996, including: (i) converting airborne recorders from Exabyte to hard disk, recording full 16-bit data, (ii) installing baseplate bolts to reduce thermal deformation, and adding temporary strain gauges to monitor structural behavior, (iii) adding a continuous in-flight N₂ purge to the spectrometer to protect the internal optics from condensation, (iv) installing "descent mode" heaters to key areas (perhaps to include the primary and first folding mirrors), re-routing power from the blackbody controllers after data collection is finished, (v) adding an air flow barrier (boot) between the base of the scanhead and the superpod skin, (vi) thermally isolating the blackbodies from the scanner structure, to reduce cooling load on the overall system, (vii) finishing pre-flight scanner cart, which will ease handling of the scanhead (reduce risk of dropping) and allow more precise alignment of the 20" hemisphere during pre-flight, (viii) installing a temporary quartz window in the temperature chamber, and interfacing to the 20" hemisphere and collimator (more permanent installation to follow), and (ix) replacing the door seal and hinges on the chamber, and implementing water-purge procedures during tests.

The pre- and post-TARFOX calibration of the CAR was conducted by Tom Arnold using both the 48-inch integrating hemisphere and 6-foot sphere as the

source. Additional tests (post-TARFOX) were done to investigate how repeatable the calibration is (day to day) and to investigate the stability of the offset values and significance of their differences for the different gain settings of each channel. Results thus far indicate good stability in both the radiance/voltage values as well as the offsets. Preliminary analysis suggests that pre-TARFOX calibration was successful. However, some problems were encountered with the filter wheel channels, which have been failing intermittently. Finally, channel 9 (1.64 μm) has gone dead. This problem was investigated and subsequently fixed by Max Strange. Then, the UV calibration for CAR channel 3, using an integrating sphere provided by the SSBUV project, was conducted at the clean room in Building 21. Tests were repeated a day later to check for consistency. Due to the shape of the CAR UV channel bandpass and the non-linearity of the sphere radiance with wavelength, the central wavelength method normally used for CAR calibration was not adequate to determine the appropriate sphere radiance to use for these tests. Unfortunately the SSBUV sphere was calibrated for only one lamp level (4 lamps on) so measuring multiple lamp levels (our normal procedure) was not useful. A method was developed to determine whether the CAR signal (when viewing the sphere) was 'clipping' at a level below saturation (as do a few other bands at very high radiance levels). These UV calibration results are currently under investigation.

c. MODIS-related Services

1. Meetings

1. Michael King, Tom Arnold, Jason Li, Xu Liang, Steve Platnick, Peter Soulen and Menghua Wang attended the MODIS Atmosphere group meeting in Chincoteague, Virginia on 17-18 July 1996 and the MAS calibration meeting at NASA Wallops Flight Facility on 19 July (also attended by Tom Arnold);

2. Tom Arnold and Steve Platnick attended the SPIE meeting in Denver, Colorado on 4-9 August 1996 and both presented papers;

3. Michael King, Robert Pincus, Steve Platnick, Si-Chee Tsay and Menghua Wang attended the 1996 International Radiation Symposium in Fairbanks, Alaska on 19-24 August 1996 and King gave an invited talk on "Radiative properties of clouds determined from satellites" and the rest presented oral or poster papers;

4. Michael King attended the 14th CERES science team meeting in Fort Collins, Colorado on 11-13 September 1996 and presented a co-investigator status report;

5. Michael King, Steve Platnick, Si-Chee Tsay and Menghua Wang attended the MODIS science team meeting in College Park, Maryland on 9-11 October;

6. Michael King attended the FIRE science team meeting in Boulder, Colo-

rado on 17-18 October and presented a paper;

7. Michael King, Si-Chee Tsay and Jason Li attended the SCAR-B science symposium in Fortaleza, Brazil on 4-8 November and all three presented papers;

8. Xu Liang, Ran Song, and Menghua Wang attended the MODIS Atmosphere Group programmers meeting at the University of Wisconsin, Madison, Wisconsin on 11-13 November to collaborate on MODIS v2 algorithms;

9. Michael King, Xu Liang, Steve Platnick, Ran Song, Si-Chee Tsay and Menghua Wang attended the MODIS ATBD review in Columbia, Maryland on 19-21 November;

10. Michael King, Xu Liang, Steve Platnick, Ran Song, Si-Chee Tsay and Menghua Wang attended the MODIS Atmosphere Group meeting at Goddard on 22 November to focus on the current status and Level-3 products;

11. Steve Platnick attended many (total of 16) MODIS Technical Team meetings, MODIS/ECS Replan meetings, MODIS Discipline meetings, and MODIS Atmosphere Quality Plan meetings since the end of October.

2. *Seminars*

1. King, M. D., "Spectral absorption of solar radiation by clouds," JASON Review, La Jolla, California, 1 July 1996.

2. Pincus, R., "What controls stratocumulus cloud fraction? Lagrangian observations of cloud evolution," University of British Columbia, Vancouver, Canada, 27 August 1996.

3. King, M. D., "Earth Observing System—Science Objectives and Challenges," Goddard Space Flight Center, Greenbelt, Maryland, 18 September 1996.

4. Liang, X., "MODIS Level-3 design and development plan with wavelets and statistical methods," Goddard Space Flight Center, Greenbelt, Maryland, 22 November 1996.

III. **Data/Analysis/Interpretation**

a. *Data Processing*

The MAS Level-1B data processing has been completed on MAS-50 data by Paul Hubanks for the Alaska-April, ARMICAS (both at Goddard DAAC) and SCAR-B (at Langley DAAC) flights. This includes 10 flights from the Alaska snow/ice mapping experiment (April 1995 in Alaska), 11 flights from SCAR-B (August-September, 1995 in Brazil), and 6 out of 10 flights from ARMICAS (June 1995 in Alaska). For all future missions, Paul Hubanks will ensure that Ames will deliver the MAS Level-0 data and preliminary calibration information to him

within 1 month (approximately) after a mission. The PI from each mission will be asked to identify up to 3 “Golden Days” flown during the mission to prioritize Level-1B processing (with this basic calibration information). It should be noted that this preliminary MAS Level-1B data will not be placed in the DAAC. This scheme will get key MAS Level-1B data into the hands of MODIS scientists in a more timely manner to assist with critical algorithm development and future mission planning meetings.

Chris Moeller requested that several HDF Scientific Data Sets (SDS) should be added to the current MAS Level-1B HDF file structure. These included: (i) the MAS instrument temperature, allowing easy instrument temperature comparisons from different flights or within a given flight and (ii) the raw count value. Moeller also requested an analysis of the scaling factors used for packing and storing MAS radiance data (in an I*2 word) in the HDF file. The concern is that the radiance data might be stored to an accuracy that is smaller than the instrument noise. This could be a problem for channel 45, which is a low-noise channel that is used for high accuracy products like sea surface temperature. A compilation of typical radiance values for each channel is currently underway to make a determination if the scaling can be improved.

New calibration software from the University of Wisconsin for the infrared bands was implemented in the MAS Level-1B Processing code. Several parameters were added to the MAS Level-1B HDF file, including a central wavelength (from Wisconsin) and two temperature correction coefficients used in the Planck conversion code for the IR bands. This allows the user to convert HDF radiances into brightness temperatures in a manner consistent with the technique used in the U. Wisconsin McIDAS MAS processing system. Also the original spectral response function (SRF) data used in processing to level-1B are added to the MAS web site. It should be noted that this change will have no impact on the MAS VIS/NIR calibration (port 1 and port 2 bands).

Jason Li completed IDL routines that can plot MAS flight tracks on topographic relief maps, as shown in Figure 1. These plots contain information based on light shading and color coded elevation. In addition, the MAS quicklook imaging software package is ready for use in the upcoming WINCE and is becoming standard quicklook image processing software for future MAS field experiments. Possible use of a homomorphic filter in MAS visualization, simultaneously compressing dynamic range and contrast stretching in frequency, was also examined. It looks very promising and will be used for CAR quicklook images in the near future. On the CAR data processing, Jason Li has completed all HDF data sets for the SCAR-B field experiment from flights 1688 to 1703 and finished SCAR-B CAR Flight Logbook. The first draft of the CAR HDF User's Guide is completed and in the review process.

b. *Analysis and Interpretation*

Extensive analyses of the MAS-AVIRIS intercomparison were conducted by us-

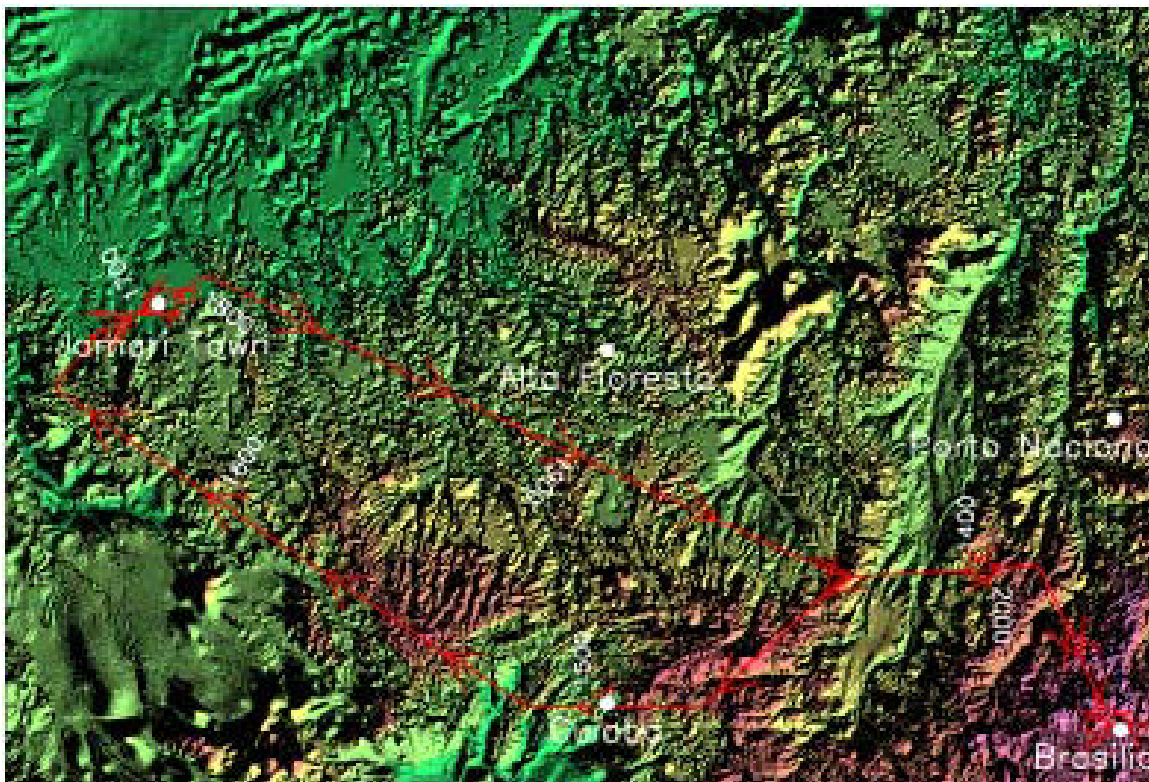


Figure 1. Ground track of the ER-2 on 4 September 1995 during SCAR-B

ing ARMICAS and SCAR-B data. A program provided by Robert Green was first modified to convolve AVIRIS bands into MAS band shapes. To minimize any biasing caused by resampling the AVIRIS data, care was taken to select relatively flat (uniform) radiance targets (standard deviation was checked to ensure uniformity). Images for ARMICAS and SCAR-B flights were reviewed and several cases were selected, with often several cases for a given flight and multiple targets in each case. In general, analyses of the MAS-AVIRIS intercomparison show reasonably good agreement for MAS bands 1-9, when viewing scenes of all or mostly terrestrial targets (little or no cloud). Comparing over mostly cloudy scenes (scenes which, on average, are much brighter), MAS values for these cases are much higher than AVIRIS at low radiance values, and often lower than AVIRIS at higher radiance values (perhaps some type of offset problem). For Bands 10-25, MAS values are almost always higher than AVIRIS, often significantly (10-20%) or more.

An example of these intercomparison is shown in Figure 2. To supplement analysis of the MAS-AVIRIS intercomparisons, the MAS temperature data (from the HDF files) were examined for all ARMICAS flights. Analysis of these data shows little variability in MAS temperature from one flight to the next and thus does not add much useful information to the analysis. Intercomparison of MAS and AVIRIS over the AVIRIS calibration site is currently planned to collaborate with Tom Chrien at JPL. MAS HDF data for the appropriate time segment (21 June 1995, after ARMICAS experiment) was received from Ames, converted to

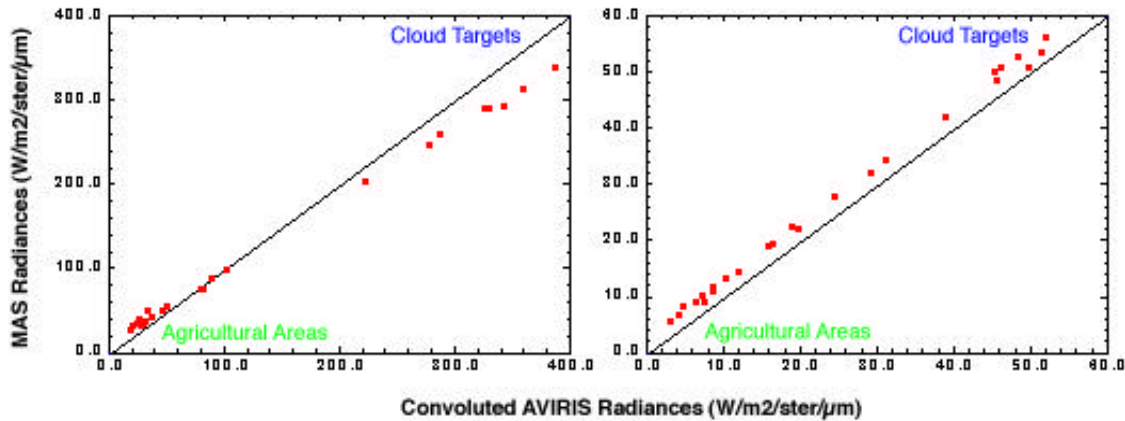


Figure 2. Comparison of SCAR-B MAS and convoluted AVIRIS measurements on 23 August 1995.

binary radiance files, and made available to JPL.

For many Earth remote sensing applications, cloud detection (or derivation of a cloud mask) is vital because the Earth is frequently covered by various types of clouds. The cloud mask being developed for MODIS (cf. ATBD by Ackerman et al.) indicates whether a given field of view has an unobstructed view of the Earth surface, or whether the pixel is cloud free but affected by cloud shadows or thick aerosol. The MAS measurements, with their high spatial resolution, will help to assess ways of convolving small scale variations to the larger scales typical of satellite sensors (like MODIS, with its primary resolution of 1 km) and serve as a prototype for cloud mask development. Figure 3 shows the results of cloud and cloud shadow masks, together with $0.657 \mu\text{m}$ reflectance and $11.02 \mu\text{m}$ brightness temperature measurements. Images of a convective cumulonimbus cloud (lower center) surrounded by lower level water clouds on the northern foothills of the Brooks Range, Alaska ($69^{\circ}7'N$, $148^{\circ}34'W$), near the town of Sagwon, were acquired on 7 June 1995. The first panel on the left ($0.657 \mu\text{m}$) shows high contrast between the optically thick (and therefore bright) cumulonimbus cloud, diffuse cirrus anvil, and remnants of the snow pack lying in ravines and topographic depressions (lower right of image), less reflective altocumulus clouds (upper and center portion of image), and dark tundra. The second panel ($11.02 \mu\text{m}$) appears quite cold (low radiance) in the coldest portion of the cumulonimbus cloud (-50°C), warmer at the top of the altocumulus cloud (-18°C), where the cloud must be composed of supercooled water rather than ice (according to the 1.609 and $1.879 \mu\text{m}$ channels, not shown), and warmest at the surface ($+17^{\circ}\text{C}$). By comparing to the 0.657 and $11.02 \mu\text{m}$ images, the detection of cloud shadow mask (blue color in the third panel) and cloud mask (yellow color in the last panel) was very successful.

In the springtime burning season in Brazil, thick haze is generated by burning of cerrado and primary forest, producing much haze as well as burning and smoldering fires and clouds. Figure 4 shows an example of the application of the cloud mask to such biomass burning aerosols. The MAS observations shown in Figure 4 were obtained for a $66 \times 37 \text{ km}$ section of the ER-2 flight line from

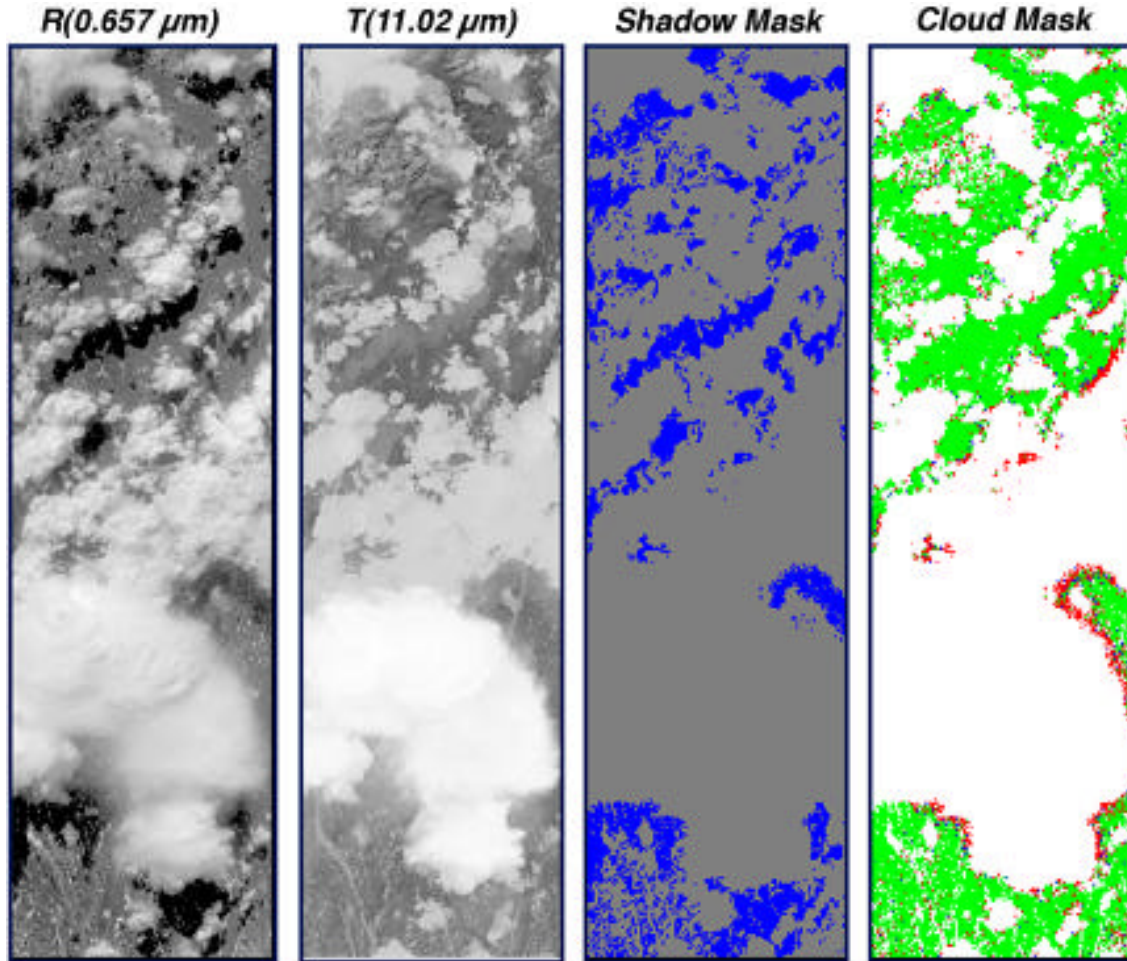


Figure 3. Preliminary results of cloud and cloud shadow masks derived from the MAS measurements obtained on 7 June 1995 during ARMCAS.

Cuiabá to Vilhena (2000 scan lines between 15:25:02 and 15:50:10 UTC). At $0.55 \mu\text{m}$ it is difficult to see the ground due to the heavy smoke and aerosol from extensive biomass burning. At $0.87 \mu\text{m}$ (second panel from left), on the other hand, surface reflectance is high and the haze is transparent, except where the ground has already been burned and is dark from burn scars. At $2.14 \mu\text{m}$ (third panel), the burn scars are again quite reflective, as if often the case over pavement in cities. The resultant aerosol mask (last panel) was derived from a combination of tests on 12 different MAS channels. Most of the scene is classified as high confident clear (red in aerosol mask), failing to detect the heavy aerosol but correctly noting that this scene is not composed of cloud (as the first panel might suggest from casual inspection).

CAR retrievals of single scattering albedo ω_0 rely on the same physical principles as do simultaneous retrievals of cloud optical thickness (τ_c) and effective particle radius (r_e) made from above cloud reflectance (i.e., visible and near-IR) measurements. Above-cloud measurements employ measurements of radiance received at a detector (which has been reflected by the entire cloud layer) normal-

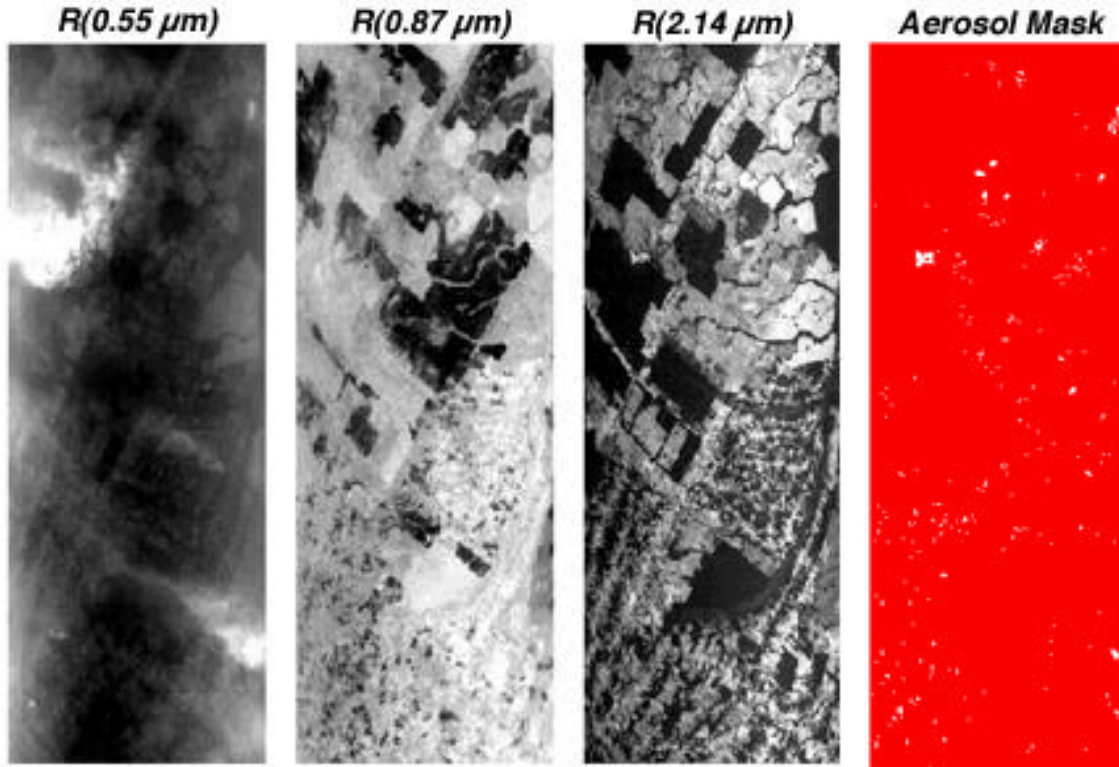


Figure 4. Preliminary result of cloud mask, with indication of heavy aerosol loading (or aerosol mask), derived from the MAS measurements obtained on 4 September 1995 during SCAR-B.

ized by the incoming solar flux and the viewing- and illumination-geometry dependent anisotropy factor. CAR measurements are made in the diffusion domain, which simplifies this process, allowing us to normalize the upwelling radiance (which has been reflected by the portion of the cloud below the observation position) by the downwelling radiance. In both instances, as absorption increases, τ_0 becomes more important and τ_c less important in determining the reflectance of a cloud layer. In the limit of very large distances above cloud base, the in-cloud intensity ratio at absorbing wavelengths does not depend on τ_c , just as the above-cloud reflectance of very thick clouds at weakly absorbing near-IR wavelengths used to retrieve effective radius is not sensitive to the optical thickness at visible wavelengths. Similarly, CAR estimates of τ_0 represent a weighted average over all scattering and absorbing components in the reflecting portion of the cloud (i.e., the part of the cloud between the observation point and cloud base). Figure 5 shows the ratio of zenith to nadir intensity at a non-absorbing ($0.65 \mu\text{m}$) and absorbing ($2.14 \mu\text{m}$) wavelength for various values τ_c and r_e . This figure may be compared with the simulations of above-cloud visible and near-IR radiance used in τ_c - r_e retrievals (see, for example, the classical Figure 2 of Nakajima and King 1990); the figures are nearly identical in character.

Surface bidirectional reflectance obtained by the CAR was studied extensively from the SCAR-B measurements. Since the reflectance of vegetation increases dramatically from visible to near-infrared regions, we have chosen CAR meas-

urements at $0.87 \mu\text{m}$ as an example for discussion, as shown in Figure 6. In all

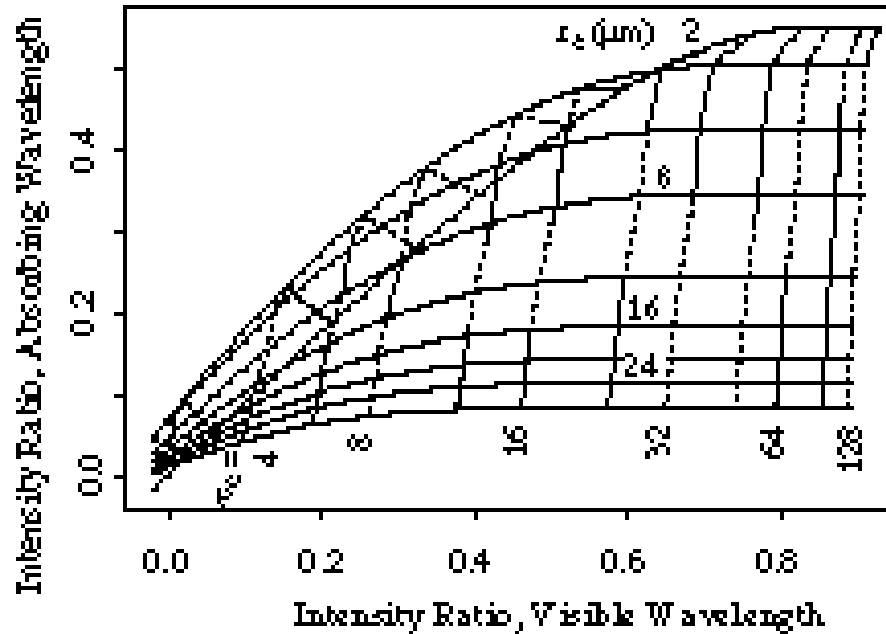


Figure 5. Intensity ratio of simulated CAR radiance for various optical depths and effective particle radii at 0.65 and $2.14 \mu\text{m}$.

polar plots, values at the edge of the outer circle represent the azimuth angles and those radials for zenith angles (zenith at the center and horizon at the edge). The sun is located in the $0^\circ - 180^\circ$ azimuthal plane. Two striking features appear clearly in Figure 6a: a highly symmetrical pattern and a strong reflection in the anti-solar plane. Data presented in Figure 6a are one of many circles obtained on 18 August 1995 at Brasilia for cerrado, in which the ground coverage is generally sparse. An average of data from all circles will further smooth and symmetrize the bidirectional reflectance pattern, yielding statistics in representing this type of surface. At the time these measurements were acquired, the sun was illuminating the scene at an average solar zenith angle of 59° . The observed strong backscattering peak around $\theta = 60^\circ$ in the principal plane is known as the “hot spot” or the “opposition surge.” For this case ($0.87 \mu\text{m}$) the reflection function has a value as high as 56%. The surface anisotropy retains similar patterns but becomes less pronounced in the visible regions due to chlorophyll absorption. Figure 6b, obtained on 25 August 1995 at Cuiabá for dense forest conditions, reveals an even better degree of symmetry, compared to Figure 6a, due to surface homogeneity. Similarly, this pattern holds for measurements over a dense smoke layer (Figure 6c) obtained on 6 September 1995 at Porto Velho. However, the bright spot diminished due to a weak direct backscattering peak (glory) and an enhancement in multiple scattering. Figure 6d also shows a different bidirectional reflectance pattern at $0.67 \mu\text{m}$ channel. These angular and spectral dependencies can be utilized to retrieve either surface characteristics or aerosol microphysical and optical properties (e.g., size distribution and single-scattering parameters), if proper physical and radiation models are used.

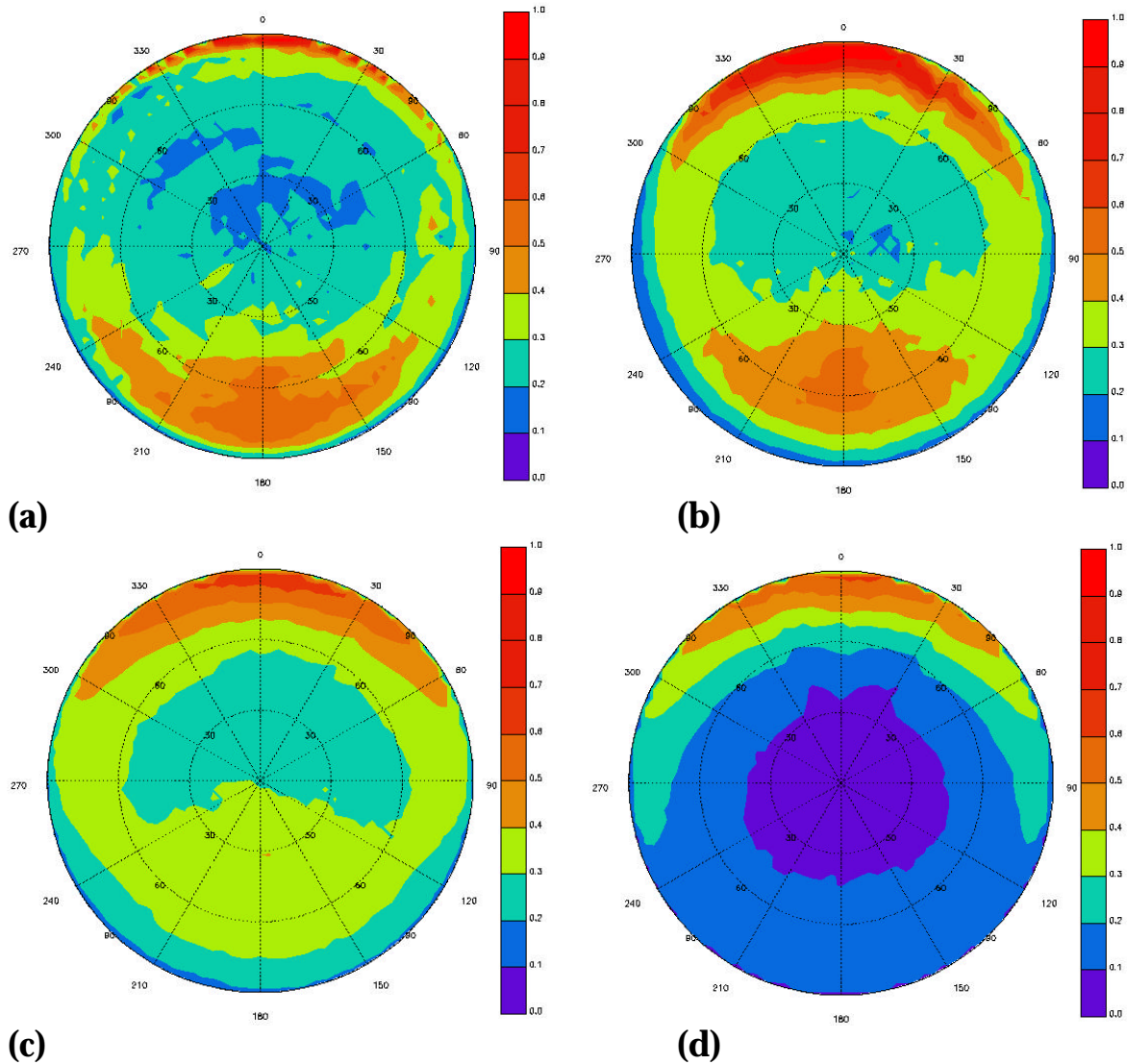


Figure 6. Measurements of bidirectional reflectance at $0.87 \mu\text{m}$ for (a) cerrado (18 August), (b) dense forest (25 August), (c) smoke layer (6 September), and (d) same as (c) but for $0.67 \mu\text{m}$, during SCAR-B.

IV. Anticipated Future Actions

- a. Continue to work on the MODIS v2 cloud retrieval algorithm delivery, to include cloud mask interface, ice/water cloud logic tree, and QA flags;
- b. Extend retrieval libraries to include ice cloud models for the MODIS v2 software delivery;
- c. Continue to analyze MAS, AVIRIS, and CLS data gathered during the ARM-CAS campaign, as well as AVHRR, University of Washington C-131A in situ data, and surface data, all with the express purpose of helping to develop the MODIS cloud masking algorithm;

d. Continue to analyze MAS, AVIRIS, and CLS data gathered during the US-Brazil SCAR-B campaign, as well as University of Washington C-131A in situ and radiation data to study aerosol mask and aerosol-cloud interactions;

e. Continue to analyze surface bidirectional reflectance measurements obtained by the CAR during the Kuwait Oil Fire, LEADDEX, ASTEX, SCAR-A ARMCAS, and SCAR-B experiments, as well as analyze CAR diffusion domain data from MAST and FIRE-87;

f. Start to analyze MAS, HIS, and CLS data gathered during the NASA SUCCESS field experiment in Kansas from 8 April to 10 May 1996, focusing on radiative properties of cirrus clouds and contrails;

g. Continue to work on the file spec for the MODIS joint atmosphere level-3 products.

V. Problems/Corrective Actions

No problems that we are aware of at this time.

VI. Publications

1. King, M. D., and M. K. Hobish, 1996: Satellite instrumentation and imagery. *Encyclopedia of Climate and Weather*, S. H. Schneider, Ed., Oxford University Press, 652–655.

2. King, M. D., W. P. Menzel, P. S. Grant, J. S. Myers, G. T. Arnold, S. E. Platnick, L. E. Gumley, S. C. Tsay, C. C. Moeller, M. Fitzgerald, K. S. Brown and F. G. Osterwisch, 1996: Airborne scanning spectrometer for remote sensing of cloud, aerosol, water vapor and surface properties. *J. Atmos. Oceanic Technol.*, **13**, 777–794.

3. Tsay, S. C., P. M. Gabriel, M. D. King and G. L. Stephens, 1996: Spectral reflectance and atmospheric energetics in cirrus-like clouds. Part II: Applications of a Fourier-Riccati approach to radiative transfer. *J. Atmos. Sci.*, **53**, 3450–3467.

4. Platnick, S., P. A. Durkee, K. Nielson, J. P. Taylor, S. C. Tsay, M. D. King, R. J. Ferek and P. V. Hobbs, 1997: The role of background cloud microphysics in ship track formation. *J. Atmos. Sci.*, in press.

5. Wang, M., and M. D. King, 1997: Correction of Rayleigh scattering effects in cloud optical thickness retrievals. *J. Geophys. Res.*, submitted.

6. Platnick, S. E., P. Abel and M. D. King, 1996: The effect of water vapor absorption on integrating sphere output radiance and consequences to instrument calibration, *Extended Abstract, SPIE*, Denver, Colorado, 4-9 August.

7. Arnold, G. T., M. Fitzgerald, P. S. Grant, S. E. Platnick, S. C. Tsay, J. S. My-

ers, M. D. King, R. O. Green and L. Remer, 1996: MODIS Airborne Simulator radiometric calibration. *Extended Abstract*, SPIE, Denver, Colorado, 4-9 August.

8. King, M. D., S. C. Tsay and P. V. Hobbs, 1996: Arctic Radiation Measurements in Column Atmosphere-surface System (ARMCAS). *Extended Abstract*, International Radiation Symposium, Fairbanks, Alaska, 19-24 August.

9. Pincus, R., M. D. King and S. C. Tsay, 1996: In situ measurements of the absorption of solar radiation in stratiform water clouds. *Extended Abstract*, International Radiation Symposium, Fairbanks, Alaska, 19-24 August.

10. Pincus, R., A. Marshak, A. Davis, M. D. King and W. J. Wiscombe, 1996: Diffusion domain retrievals of single scattering albedo inside thick but variable clouds. *Extended Abstract*, International Radiation Symposium, Fairbanks, Alaska, 19-24 August.

11. Platnick, S., E., 1996: The scales of photon transport in cloud remote sensing problems. *Extended Abstract*, International Radiation Symposium, Fairbanks, Alaska, 19-24 August.

12. Tsay, S. C., P. M. Gabriel, M. D. King and G. L. Stephens, 1996: Spectral reflectance and atmospheric energetics in cirrus-like clouds. *Extended Abstract*, International Radiation Symposium, Fairbanks, Alaska, 19-24 August.

13. Wang, M., and M. D. King, 1996: Rayleigh scattering effects on cloud optical thickness retrievals. *Extended Abstract*, International Radiation Symposium, Fairbanks, Alaska, 19-24 August.

14. King, M. D., S. C. Tsay, J. Y. Li, and S. A. Ackerman, 1996: Radiative properties of smoke and aerosol during SCAR-B. *Extended Abstract*, SCAR-B Science Symposium, Fortaleza, Brazil, 4-8 November.

15. Tsay, S. C., M. D. King, and J. Y. Li, 1996: SCAR-B airborne spectral measurements of surface anisotropy. *Extended Abstract*, SCAR-B Science Symposium, Fortaleza, Brazil, 4-8 November.

16. Li, J. Y., S. C. Tsay, M. D. King, and G. T. Arnold, 1996: Radiometric comparisons between MAS and AVIRIS imaging spectrometers during SCAR-B field experiment. *Extended Abstract*, SCAR-B Science Symposium, Fortaleza, Brazil, 4-8 November.

17. Ji, Q., S. C. Tsay, Y. J. Kaufman, and G. E. Shaw, 1996: SCAR-B ground-based measurements of aerosol microphysics in Cuiabá. *Extended Abstract*, SCAR-B Science Symposium, Fortaleza, Brazil, 4-8 November.